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# Base case analysis of a HYSOL power plant

J. F. Servert[a,*], E. Cerrajero[b], D. López[b], S. Yagüe[b], F. Gutierrez[c], M. Lasheras[d], G. San Miguel[e]

[a] Industrial Engineering Ph.D., CEO of Investigación, Desarrollo, e innovación energética IDIE. *Pza. Manolete 2, 11 C, 28020–Madrid (Spain)*

[b] *Researcher at Investigación, Desarrollo, e innovación energética IDIE*

[c] *Industrial Engineer, project engineer at Cobra Instalaciones y Servicios. C/ Cardenal Marcelo Spínola 10, 28016–Madrid (Spain)*

[d] *Industrial Engineer, project coordinator at Cobra Instalaciones y Servicios. C/ Cardenal Marcelo Spínola 10, 28016–Madrid (Spain)*

[e] *Chemistry Ph.D., Professor at Universidad Politécnica de Madrid UPM, Departamento de Ingeniería Energética y Fluido Mecánica, Escuela Técnica Superior de Ingenieros Industriales (ETSII). C/ José Gutiérrez Abascal 2, 28006–Madrid, Spain*

**Abstract**

Concentrating solar power (CSP) plants are regarded as an alternative solution for electricity generation. The main drawback of this technology is related to the intermittent and seasonal nature of the solar irradiation. As a consequence, most CSP plants have a reduced capacity factor and difficulties to supply electricity on demand to the grid.

The integration of energy back-up systems may contribute to increasing power generation capacity and stability. Several options are being developed at present which are based on the incorporation of Thermal Energy Storage (TES) and also the use of auxiliary fuels. HYSOL is a new concept in CSP technology that relies on the integration of a molten salt TES system operating in hybrid mode with a biogas turbine with a Heat Recovery System (HRS). This paper illustrates the methodology and first results obtained during the development of the static model, considering a Base Case of HYSOL configuration. The study of this Base Case allows evaluating the impact of HYSOL technology, providing preliminary plant information and defining the required tools to be used in the project.



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*Keywords:* Hybridization, CSP, thermal energy storage, gas, biogas, AGT, gas turbine

* Corresponding author. Tel.: +34-91-383-58-20; fax: +34-91-767-01-29.
*E-mail address:* jservert@idie.es



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**Nomenclature**

| | |
|---|---|
| AGT | Aeroderivative Gas Turbine |
| CSP | Concentrated Solar Power |
| DNI | Direct Normal Irradiation |
| HRS | Heat Recovery System |
| HTF | Heat Transfer Fluid |
| IPR | Intellectual Property Rights |
| ISCC | Integrated Solar Combined Cycle |
| LHV | Lower Heating Value |
| MS | Molten Salts |
| SGS | Steam Generator System |
| TES | Thermal Energy Storage |

## 1. Introduction

Renewable energies are often criticized for not being able to produce supply power to the electrical grid in a manner that is stable, firm and reliable, as they often depend on meteorological circumstances that have a variable or stochastic component. Several options have arisen to minimize the effect of fluctuating solar resource, which can be divided into Thermal Energy Storage (TES) and hybridization with other fuels. This difficulty can find a proper and viable solution through hybrid CSP/biomass plants. Thus, the market is showing a strong interest in hybrid technologies for power generation.

Molten salts storage systems are the most extended solution inside thermal storage field [1], although other solutions (phase-change materials, concrete, sand, etc.) are also under development. Regarding hybridization, most extended solution is ISCC (Integrated Solar Combined Cycle) since five commercial ISCC are currently under operation [2]. However, ISCC have several restrictions in the maximum solar power installation to avoid performance penalties in the turbines. Due to this fact, industry players are now researching on how CSP can be hybridized with biomass energy to achieve 100 % renewable and sustainable energy. This kind of hybridization has gained importance in the last years and there are some examples of hybrid power plants with the goal of making renewable energies more manageable, as in Les Borges Blanques (biomass-CSP hybrid plant) [3] and HIBIOSOLEO project configuration [4].

## 2. Description of HYSOL configuration

Previous studies on integration of Aeroderivative Gas Turbines (AGT) have been analyzed as a result of poor fuel utilization efficiency and reduced solar contribution in ISCCs [5]. In order to integrate molten salts storage and AGTs in a solar power plant, HYSOL project proposes the configuration illustrated in Fig. 1.

HYSOL configuration is a novel concept that unites the two main options available to maximize solar thermal power plants production, overcoming the CSP technology limitations and increasing its contribution in the global electric market.

HYSOL configuration will be able to work as a peak-load, working with the sun energy during the day, with the stored energy during the night and with the gas turbine when the storage system is empty; or as a peak-base, and working with both turbines (steam and gas) at the same time.

Since CSP technology is already proved to be technically feasible, demonstrative projects like HYSOL are needed in order to take solar thermal power plants to the next level. Consequently, the most important impact of HYSOL CSP/biomass hybrid project on CSP industry will be cost reduction obtained through continuous technological development and higher production rates.

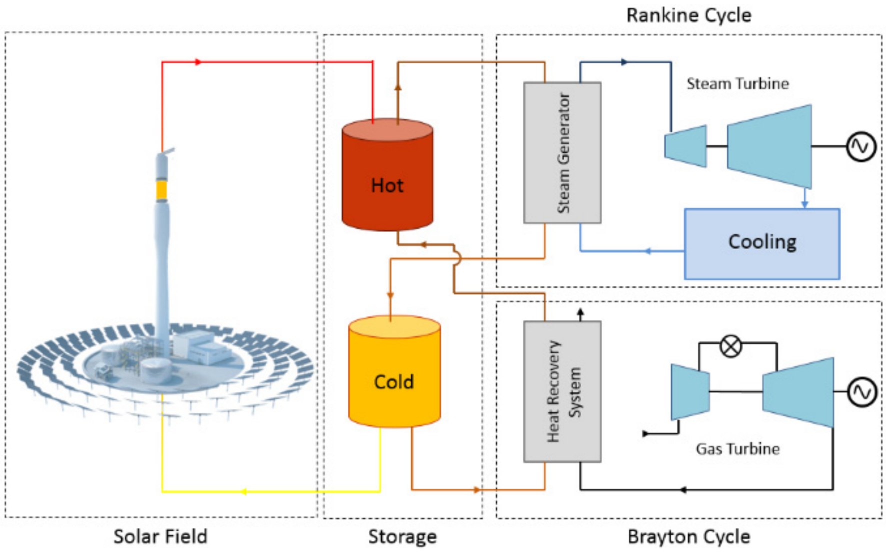


Fig. 1. HYSOL configuration for a CSP hybrid power plant using a central tower solar field

## 3. Base case analysis

### *3.1. Parameters set-up*

A Base Case has been selected as a benchmark in HYSOL project to measure the impact of HYSOL configuration, providing preliminary plant information and defining the required tools to be used in the project. The characteristics of the Base Case of HYSOL configuration are illustrated in Table 1.

Table 1. Plant characteristics of HYSOL Base Case

| | **Base Case** |
|---|---|
| Location | Almería, Spain |
| Tower height [m] | 162 |
| Number of heliostats | 4,954 |
| Total reflective area [$km^2$] | 0,7 |
| Thermal storage capacity [h] | 15 |
| **Steam Turbine** | |
| Steam Turbine power capacity [MWe] | 50 |
| Efficiency [%] | 41 |
| Pressure [bar] | 123.3 |
| Temperature [ºC] | 531.2 |
| Steam mass flow [kg/s] | 45.1 |
| **Gas Turbine** | |
| AGT power capacity [MWe] | 50 |
| Efficiency [%] | 41.5 |
| LHV [kJ/kg] | 46,280 |
| Fuel mass flow [kg/s] | 2.6 |

The climate data correspond to Almería, Spain (Lat: 36.8°; Long: -2.4°); a summary is shown in Table 2.

Table 2. DNI monthly values

| Month | DNI [kWh/m$^2$] |
|---|---|
| January | 132 |
| February | 125 |
| March | 169 |
| April | 179 |
| May | 182 |
| June | 210 |
| July | 206 |
| August | 180 |
| September | 149 |
| October | 125 |
| November | 125 |
| December | 109 |
| TOTAL: | 1,891 |

To evaluate the behavior of a HYSOL power plant, a static model has been developed to simulate power plant production and gas consumption for the Base Case. The results are compared with an equivalent conventional solar thermal power plant (no gas turbine) burning the same amount of gas. The cases studied are summarized below:

- A “Solar Only” plant with the solar field described in Table 1 but without gas consumption (Fig. 2)
- A HYSOL plant, as described in Table 1, with the operation criteria defined in Fig. 3
- A “Gas Heater” plant with the solar field described in Table 1, burning gas in a HTF heater (instead of AGT) up to the amount used in the HYSOL plant

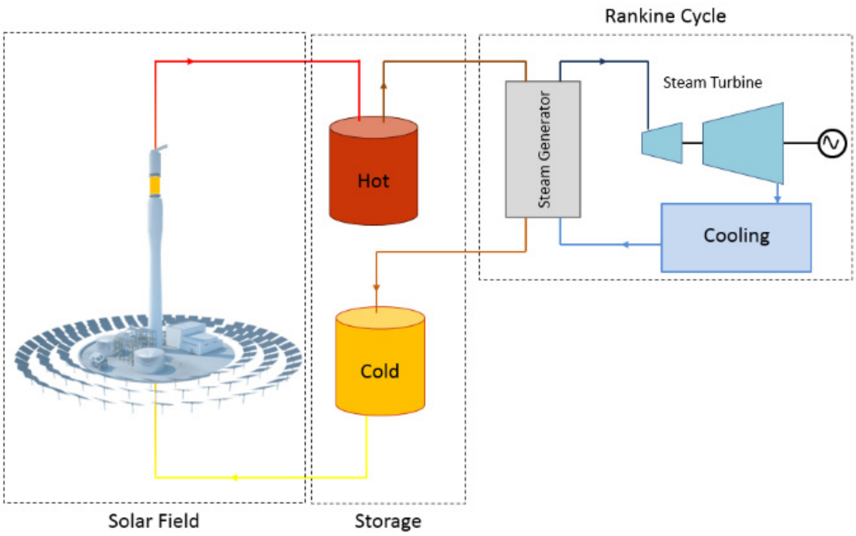


Fig. 2. Diagram of a CSP “Solar Only” plant

### 3.2. Static model of Solar Only and Gas Heater power plants

The static model of the Solar Only power plant corresponds to a state-of-the-art solar tower thermal power plant including the solar field and the steam turbine defined in Table 1.

The Solar Only power plant operation is very similar to the Solar Two TSS [6]. During solar collection, cold salt is pumped from the cold tank through the solar receiver system, where it is then heated with concentrated solar irradiation and flows by gravity into the hot tank at its nominal temperature. In order to provide heat to the Rankine cycle, the hot salt is pumped from the hot tank, through the SGS, and back to the cold tank.

In the Gas Heater power plant, restraining at the same time the solar input (to that of Solar Only) and equalling the gas consumption of HYSOL's AGT would bring the configuration to theoretical capacity factors above 100% if the same steam turbine were used, so the power of the turbine was left as a degree of freedom in the simulation. The production figure was extrapolated with the average gas usage efficiency for comparison purposes only.

### 3.3. Static model of HYSOL power plant

The static model of a HYSOL power plant has been developed using Thermoflex® software and attending to the operation criteria diagram in Fig. 3. Power plant main equipment has been defined with the preliminary design characteristics developed during the project and they are not shown in this paper due to IPR restrictions.

In order to simulate a full year, a first set of operational restrictions have been defined and applied in the model:

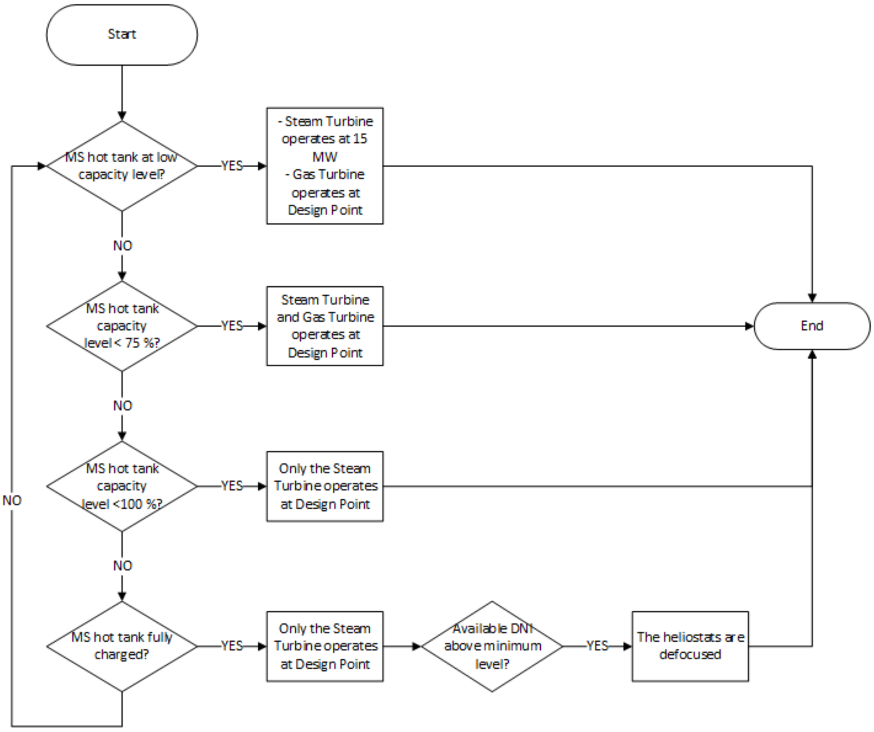


Fig. 3. Operation criteria focused on the MS hot tank flow chart

Neither the plant configuration nor the operation strategy are optimal nor unique; for each location, solar field, TES and AGT sizing shall be tailored to the solar resource, gas price and demand profile. The operation strategy in Fig. 3 has been defined to illustrate the differences between HYSOL and the other power plant configurations under simplified conditions. The effect of the operation strategy and its effect on different parameters (fuel usage, minimum solar energy dumping, efficiency, dispatchability, power output, costs, etc.) will be evaluated at later project stages.

## 4. Results for the configurations under study

The modeling and simulation of the plant configurations have been carried out for one year hourly input data. The results are presented for the HYSOL configuration and compared to the other configurations to evaluate the differences in terms of power production and gas usage (Table 3).

Table 3. Comparison of results for a solar thermal power plant with HYSOL, with a Gas Heater and without gas usage (Solar Only)

| Specification | HYSOL | Gas Heater | Solar Only |
|---|---|---|---|
| Normalized† Rankine annual energy output | 1.47 | 2.37 | 1 |
| Normalized Brayton annual energy output | 1.37 | 0 | 0 |
| Normalized total annual energy output | 2.85 | 2.37 | 1 |
| Normalized‡ Annual fuel consumption | 0.76 | 0.76 | 0 |
| Normalized solar input | 1 | 1 | 1 |

Figures 4 and 5 illustrate a comparison of a typical summer and winter day production profile in the case of a HYSOL configuration and Solar Tower only. Normalization is made dividing by solar only results or input as corresponds.

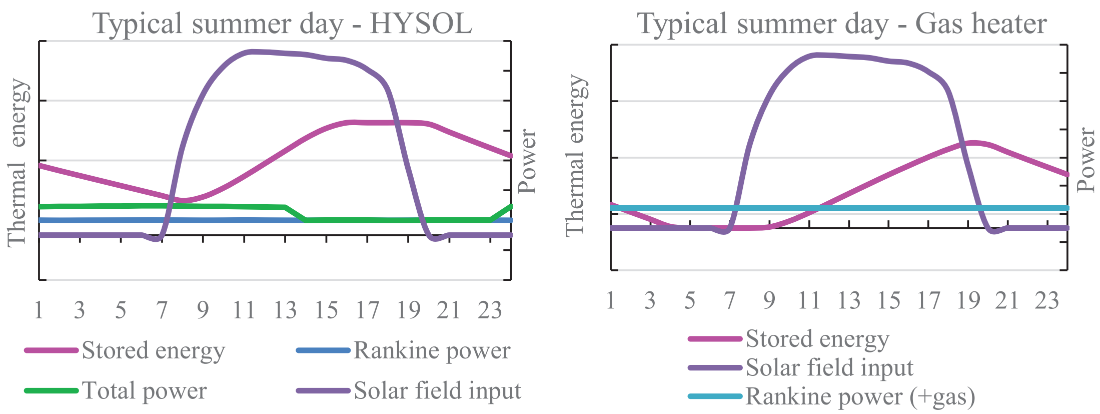


Fig. 4. (a) 24 hours summer cycle with HYSOL and (b) 24 hours summer cycle with Gas Heater

During summer, both the solar thermal power plant with HYSOL and with Gas Heater enable the steam turbine to provide firm power and minimize partial loads operation. The thermal energy storage is full several hours per day, and is never totally empty in summer. HYSOL's gas turbine operating hours can be chosen to match the demand profile; the simplified operation criteria used for this paper simply stops when the TES is full.

During a winter day with variable solar resource, a Solar Only power plant production presents time intervals when the steam turbine is turned off because the storage is discharged. These situations do not occur with the HYSOL configuration or an equivalent gas usage in a Gas Heater, reducing the number of start-ups and shut-downs in the steam turbine and increasing its efficiency. The power supplied by HYSOL is higher, however, as both turbines can be working full time. As shown in Fig. 5, with HYSOL the TES is not totally empty in winter either, so there is margin to optimize of the overall configuration.

† The electricity output has been normalized with the electricity output of the Solar Only power plant under the same conditions
‡ The thermal input has been normalized with the solar field thermal input of the Solar Only power plant under the same conditions

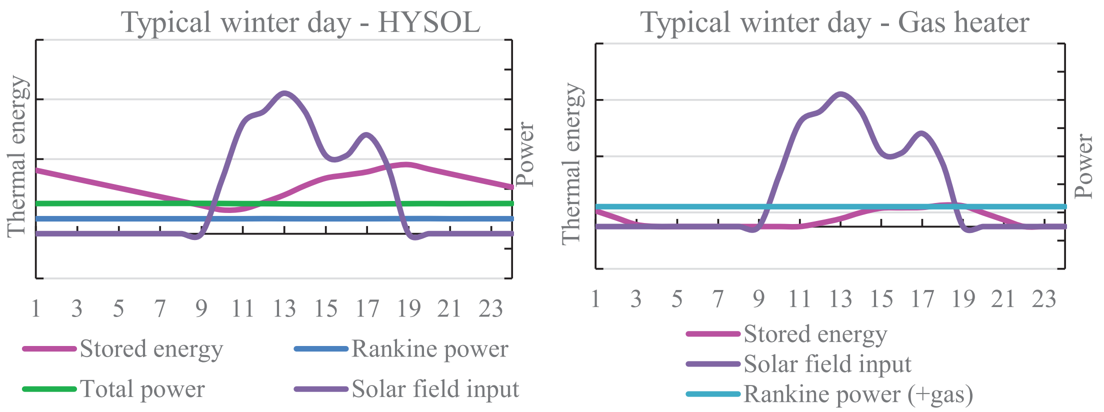


Fig. 5. (a) 24 hours winter cycle with HYSOL and (b) 24 hours winter cycle with Gas Heater

Solar thermal power plants with HYSOL configuration offer advantages compared to Gas Heater solar plants, and even more if compared to Solar Only. On the electrical side, the electrical power output doubles its value thanks to the AGT. On the thermal side, HRS is able to load the thermal storage system using hot exhaust gases of the biogas turbine thus improving fuel utilization efficiency and storage dispatchability. The enhanced efficiency in the thermal storage results in the extension of plant operating time regardless the climate conditions. Moreover, the number of start-ups and shut-downs in the steam turbine is reduced, thus improving the dispatchability of the turbine and providing valuable firm power during peak demand periods.

Figure 6 illustrates the annual energy output for a plant configuration with and without HYSOL and the benefits of a HYSOL configuration in terms of energy production. The overall energy output of HYSOL is lower in summer because, for the configuration and operation criteria used, the gas turbine stops during more hours due to a full TES.

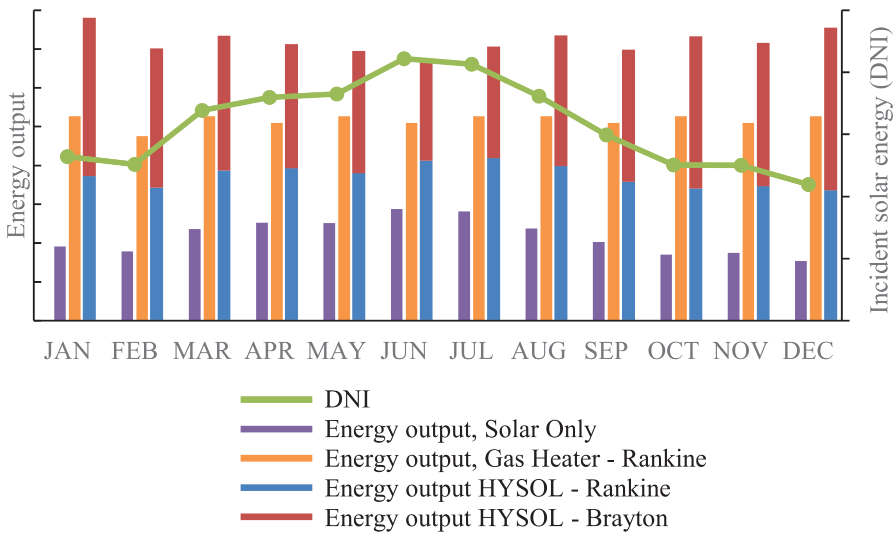


Fig. 6. Monthly energy output for the different configurations tested

## 5. Conclusions

To preliminarily evaluate the behaviour of a HYSOL power plant, a static model has been developed to compare in terms of power production and gas usage a solar thermal power plant with and without HYSOL configuration simulated under the same thermal input conditions.

A methodology to model the base case has been defined to be used during HYSOL project. The results are preliminary. Variation in several inputs and equipment definitions must be included in future simulations (different locations, solar field size, receiver thermal power, storage capacity, operation strategy, etc.) to evaluate possible improvements.

During a typical summer day, base demand can be fulfilled with HYSOL configuration or with a Gas Heater but HYSOL has the capability of following demand while keeping a firm production in the steam turbine at a nominal point, being the electrical output higher for the same gas usage; the TES is not empty at any time in summer for these configurations. In the Solar Only case, the storage is not enough to keep the steam turbine working at a nominal point.

During a typical winter day, the electricity production in both the steam turbine and HYSOL's gas turbine can be maximal. In HYSOL, the TES is not completely full, but neither completely empty most days.

Steam turbine shut-down/start-up operations can be avoided all through the year by including HYSOL configuration. Regarding annual electricity production results, HYSOL configuration can reach nearly 100% capacity factor in the steam turbine. Gas turbine electricity output can be similar to that of the steam turbine (if the operation criteria in Fig. 3 is applied) and the annual average performance rate from gas to electricity is in this case over 47 % (considering both the increase of steam turbine and gas turbine electricity production). Total electricity output is a 17% higher in HYSOL than in the Gas Heater configuration (same amount of gas is used).

In conclusion, HYSOL configuration improves the general working conditions of the steam turbine and increases the usage of the thermal storage. HYSOL configuration optimizes energy efficiency and power availability, flexibility and dispatchability. The integration of a HRS and an AGT enables the plant to generate electricity at any time of the day and in all weather conditions. This configuration will be able to work as a peak-load, working with the sun energy during the day, with the stored energy during the night and with the gas turbine when the storage system is empty; as a peak-base working with both turbines (steam and gas) at the same time; or follow a predefined schedule.

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